LESSON 4 - ENERGY MANEUVERING

The pilot with the best energy management skills will usually win the fight.

Reading:

Shaw **pp. 175 (last paragraph)-177**
11-F16 **Sec 4.6.5.3-4.6.5.3.3 (p. 54)**
Bretana pp. 12-20

Problems/Questions:

Work on Problem Set 1

Objectives:

4-1 Understand how conservation of mechanical energy is related to aerial combat.
4-2 Know which of the four aerodynamic forces are non-conservative.
4-3 Understand what specific excess power is and how it is used in aerial combat.
4-4 Be able to interpret specific excess power overlays for a single aircraft and an aircraft comparison for combat.
4-5 Know the three primary factors that help you accelerate to regain lost energy in the shortest time.

Last Time: Turn Performance
Rate/Radius
Level vs. Oblique

Today: Energy Maneuvering
Mechanical energy
Total energy
Specific excess power

Equations: $r \propto V^2/G_r$, $\omega \propto G_r/V$, $P_s = (T-D)V/W$

Think back on the F-16 loop video from last lesson.
Why did the airspeed vary? Kinetic/potential tradeoff.

$K = ½\ mv^2$, $U = mgh$, $E = K+U$

Throw a ball up. Why did it stop? $\Delta E = 0$ => on the way up, K↓ and U↑; on the way down, K↑ and U↓.

Fighting is a constant K/U tradeoff.

In an oblique fight, starting at the bottom and progressing through the turn, G_r↑ (because God's G hurts you less), U↑ (as you climb), K↓ (you get slower) => V↓ => r↓, ω↑.

As you go up, $G_r\downarrow$, $U\downarrow$, $K\uparrow$ => $V\uparrow$ =>$r\uparrow$, $\omega\downarrow$.

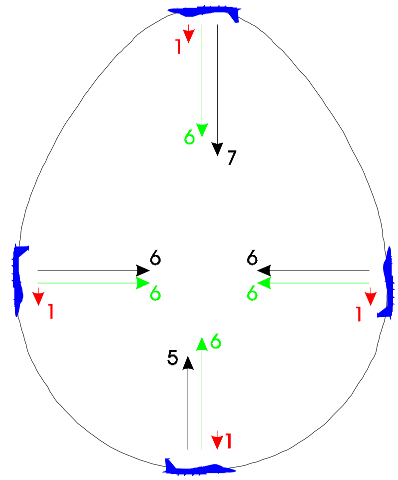
The energy egg/tactical egg concept ties this together.

As alluded to above, these scenarios are only a simplistic solution. Look at a max G, corner velocity level turn. How long can this last? NOT LONG. If we're level, potential energy is constant, but as we bleed off airspeed in the high g turn, we also bleed energy. But this says that $\Delta E < 0$! Are we saying that energy is not conserved???? Isn't energy always conserved?

Red is the G due to the earth

Green is the G on the G meter

Black is the radial G, the G responsible for turning the jet.



Remember that E is *mechanical* energy only. It doesn't include losses due to frictional forces or gains due to conversions of other types of energy within the system.

Slide a box on the table. Friction stops it. Drag = Friction = Non-conservative force.

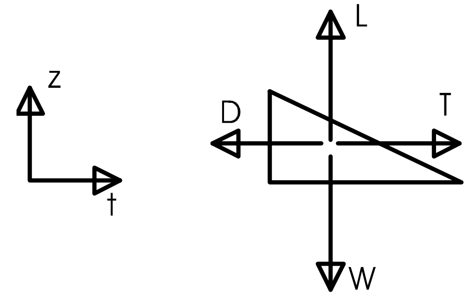
$|W| = |F \cdot d| = |F|\,|d| \cos\theta$, and has units of energy.

$\Delta E = W_{nc}$

Is thrust a non-conservative force? Can you accelerate in level flight when you add power? If you can, you're increasing the mechanical energy of the system, so thrust must be a non-conservative force.

Since drag always acts opposite the direction of motion, the angle between the drag and displacement vectors is 180 deg, so the work done by drag is negative. Conversely, the work done by thrust is always positive. Extending this line of thought, if the net non-conservative work is negative, the jet will slow down; if the net work is positive, the jet will speed up.

An important point (foot stomper) follows:



Of the four forces of flight, which are conservative and which are non-conservative?

Weight is the only conservative force. How much work does lift do? By our definition of the lift vector, it's always perpendicular to the velocity vector. Thus, the work due to lift is $|W_L| = |L||d|\cos(90) = 0$ always. Lift NEVER accelerates or decelerates the jet (in the tangential direction). Thus, lift can never add or subtract energy from the jet.

This implies that the only way to change a jet's mechanical energy is to vary thrust and drag.

$T<D \Rightarrow E\downarrow$; $T>D \Rightarrow E\uparrow$.

To find the change in mechanical energy, we have to find the work done by all of the non-conservative forces. As we've said, weight is a conservative force, so it won't change the mechanical energy of the jet—it just transforms it from kinetic to potential and back. For the other three forces, they always act either parallel/antiparallel or perpendicular to the distance traveled, so θ is always either 0 or 90 degrees, meaning $\cos\theta$ is either 1 or 0, pretty easy numbers to work with. Lift is the force where $\theta = 90$, so the work done by lift is always zero. Thus, we have to only consider thrust and drag in our energy balance equation. Since $W = Fd\cos\theta$, and since cos q for both of these forces is 1, and since thrust adds energy and drag takes it away, the energy balance equation for a jet in flight becomes:

$$\Delta E = T\Delta d - D\Delta d = (T-D)\,\Delta d$$

This is all fine and dandy, but what a fighter pilot wants to know is <u>how fast</u> can he accelerate or climb. <u>Power</u> is the *rate of change* of energy, and will answer the fighter pilot's question. We'll tally up the power that lets us go faster and subtract the power that slows us down, and call the result *excess power*:

$$P = \Delta E/\Delta t = (T-D)\Delta d/\Delta t = (T-D)(\Delta d/\Delta t) = (T-D)V$$

A Viper and a C-5 are both at 10,000' flying at 350kts. Which one has more energy? Both kinetic and potential energy terms include mass, so with their velocities and altitudes the same, the C-5 has MUCH more energy. If the C-5 and the Viper both go into max performance climbs, the C-5's energy changes at about the same rate as the Viper's, maybe even better. Is comparing these absolute energy numbers a good way to see which jet outperforms the other? Not.

If, however, we divide out the weight from the equations and talk about the energy *per mass* of the two aircraft, then the Viper's performance advantage becomes clear. Dividing by weight gives us *specific* energy, and using specific energy in the power equation gives us specific power. It also modifies the above power equation to become

$P_s = (T-D)V/W$, which is the "flight test equation" talked about in the handout and the text.

What does it mean if $P_s >,<,= 0$? All of the quantities in the formula are positive numbers, so the sign of P_s depends upon the relationship between T and D. If T is bigger, then P_s is positive, etc. This is reminiscent of the slide I showed you last time about sustained turns vs. instantaneous turns

Show V-n chart with sustained turn overlay.

Remember, those V-n and sustained turn charts show you where thrust is equal to drag, but only give you ideas about how much greater your thrust is, not specific numbers. A chart that can give you the specific numbers is the P_s chart.

Show P_s chart (it comes from test data and computer models)

Discuss the givens for each chart (power setting, weight, G load, etc)

The nice thing about Ps is that it talks about performance on equal terms regardless of the jet type. Thus, you can overlay two charts from two different aircraft and see which one performs better and where. The one with the greater P_s at a specific altitude/airspeed combination is the better performing jet. In fact, when you get to your operational fighter squadron, you'll find that the target arms (fighter weapons school grads) have done all the math for you, and you'll be able to look up jet comparison charts.

Show jet comparison charts for F-4 vs. MiG 21

Discuss areas of advantage for each jet, what negative numbers mean, etc.

Why should Duke Cunningham have fought differently?

So, if you study these charts and manage your energy well, you'll be a first-rate fighter pilot, right? Read quotes on p 99 ("The guy who wins is the guy who makes the fewer gross mistakes." --Lt Jim "Huck" Harris, USN, USN FWS Instructor), p 182 ("The quality of the box matters little. Success depends upon the man who sits in it." –Baron Manfred von Richthofen), and "I'd rather be lucky than good!"